



Briefing: Ventilation

A Briefing on Recent Scientific Literature Focused on the Effects of Ventilation on SARS-CoV-2 Spread

Dates of Search: 01 January 2022 through 27 May 2022

Published: 7 July 2022

This document synthesizes various studies and data; however, the scientific understanding regarding COVID-19 is continuously evolving. This material is being provided for informational purposes only, and readers are encouraged to review federal, state, tribal, territorial, and local guidance. The authors, sponsors, and researchers are not liable for any damages resulting from use, misuse, or reliance upon this information, or any errors or omissions herein.

INTRODUCTION

Purpose of This Briefing

- Access to the latest scientific research is critical as libraries, archives, and museums (LAMs) work to sustain modified operations during the continuing severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic.
- As an emerging event, the SARS-CoV-2 pandemic continually presents new challenges and scientific questions. At present, the effects of **ventilation-based and other mitigation strategies on the spread of SARS-CoV-2** are also an interest area for LAMs. This briefing provides key information and results from the latest scientific literature to help inform LAMs making decisions related to these topics.

How to Use This Briefing: This briefing is intended to provide timely information about SARS-CoV-2 vaccines, variants of concern, and ventilation to LAMs and their stakeholders. Due to the evolving nature of scientific research on these topics, the information provided here is not intended to be comprehensive or final. As such, this briefing should be used in conjunction with other timely resources to ensure decision-making reflects the latest scientific understanding. Continual re-evaluation of SARS-CoV-2 policies is highly recommended as new scientific discoveries are published.

About This Briefing

- Battelle conducted a systematic search of scientific literature about SARS-CoV-2 ventilation. This briefing summarizes those findings.
- Research question:
 - What effects do ventilation and ventilation-based interventions (e.g., heating, ventilation, and air conditioning systems [HVAC]) have on the spread of SARS-CoV-2 in indoor environments?
- Dates of search: 01 January 2022 to 27 May 2022.
- Additional information about the methods used to conduct the literature search and create this briefing is included later in the document.

About REALM

REopening Archives, Libraries, and Museums (REALM) is a research project conducted by OCLC, the Institute of Museum and Library Services (IMLS), and Battelle to produce and distribute science-based COVID-19 information that can aid local decision-making regarding operations of archives, libraries, and museums.

[View reports published by REALM.](#)

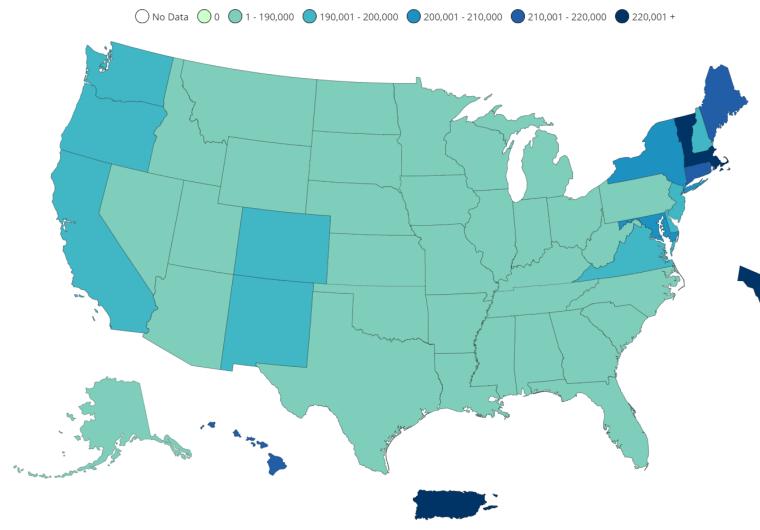
BACKGROUND INFORMATION: VACCINES AND VARIANTS

SARS-CoV-2 Vaccines

- The CDC reports updated vaccination numbers daily on a [COVID-19 data tracker](#).¹
- Three safe and effective vaccines are being distributed with emergency use authorization or full FDA approval:
 - Pfizer-BioNTech²
 - Ages 5+: 2-dose primary series and 1 booster
 - Ages 6 months-4 years: 3-dose primary series
 - Moderna³
 - Ages 6 months+: 2-dose primary series and 1 booster (18+ only)
 - Janssen (Johnson & Johnson) (J&J)⁴
 - Adults 18+: Single dose and 1 booster of Pfizer-BioNTech or Moderna vaccine
- Additional primary series/booster doses of Pfizer-BioNTech or Moderna recommended for adults 50+ and certain immunocompromised individuals.^{2, 3, 4}

To find local vaccination sites: visit [Vaccines.gov](#), text a zip code to 438829, or call 800-232-0233.

Total Doses Administered Reported to the CDC by State/Territory per 100,000 of the Total Population (as of 16 June 2022)¹



[**Vaccination rates by county are also available](#)

Variants of SARS-CoV-2

What is a Variant?

Viruses inherently replicate, which can result in genetic changes or mutations. After enough mutations occur, the new version is called a variant.^{5,6}

CDC Variants of Concern (VOC)

“A variant for which there is evidence of an increase in transmissibility, more severe disease (e.g., increased hospitalizations or deaths), significant reduction in neutralization by antibodies generated during previous infection or vaccination, reduced effectiveness of treatments or vaccines, or diagnostic detection failures.”⁵

[Information about reported cases of variants by region and state is available from the CDC.](#)

What does neutralization mean?

Neutralization is when antibodies, part of the body's defense, bind to a virus and block infection. Vaccines cause the body to build up the antibodies that inhibit viruses.⁷

Current CDC Variants of Concern in the US (as of 22 June 2022)⁵

WHO Label	Pango Lineage	First Detected	Other Names
Omicron	B.1.1.529, BA.1, BA.1.1, BA.2, BA.3, BA.4 and BA.5	South Africa	21K

SUMMARY OF FINDINGS: SYSTEMATIC SEARCH OF SCIENTIFIC LITERATURE ABOUT THE EFFECTS OF VENTILATION AND OTHER MITIGATION STRATEGIES ON SARS- COV-2

Studies About the Effects of Ventilation on SARS-CoV-2

Studies About the Effects of Ventilation on SARS-CoV-2

Practical Applications of Ventilation

- A few studies have explored how different ventilation strategies may mitigate the spread of SARS-CoV-2 in real-life settings.
 - As part of a case study using the multizone simulation tool CONTAM to model SARS-CoV-2 transmissions in a US Dept. of Energy large office prototype building, researchers also assessed the impacts of potential mitigation strategies.⁸
 - Findings identified several mitigation strategies for reducing SARS-CoV-2 risk in the most vulnerable spaces of the building, including applying 100% outdoor air ventilation, upgrading to MERV 11 or MERV 14 filters, and adding portable air cleaners (PACs) with HEPA filters in-room and in-duct germicidal ultraviolet.
 - An investigation of two COVID-19 outbreaks in a restaurant in Hong Kong found that the secondary attack rates (probability of infection after exposure within a household or other close contact) of customers were significantly lower after enhancing indoor air dilution through ventilation and installation of air purifier.⁹

Studies About the Effects of Ventilation on SARS-CoV-2

Natural Ventilation

- Several studies have examined how natural ventilation (the use of natural forces like wind and buoyancy to move air through an enclosed space¹⁰) may impact the spread of SARS-CoV-2.
 - Researchers explored how varying window opening modes (position and size) and using fans might increase ventilation efficiency and lower SARS-CoV-2 infection risk in a naturally ventilated classroom.¹¹
 - Findings suggested adding a supply fan into window openings may provide an easy, cost-effective way of improving ventilation.
 - A simulation study of a naturally ventilated classroom found that installing air deflectors on external windows (in open mode) can effectively reduce the infection risk.¹²
 - One study assessing airflow and CO₂ dispersion (used as a proxy for risk of transmission) in semi-indoor settings (i.e., restaurant terraces) found that while more ventilation is better, such settings pose unique challenges such as local flow patterns.¹³

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems and Air Filtration

- Given the evidence that SARS-CoV-2 can be transmitted through HVAC systems, many studies have examined which modes of ventilation minimize spread and how to mitigate airborne spread with differing ventilation and air filtration systems.
- Several studies have explored the use of ultraviolet (UV) technology in minimizing the spread of SARS-CoV-2 in enclosed spaces
 - One study demonstrated the effectiveness of a single pass of a UV-C air treatment device in inactivating SARS-CoV-2.¹⁴
 - Another study examining Far-UVC, (a germicidal ultraviolet-C radiation with a wavelength of 200 to 230 nm) in a room-size chamber determined that it can effectively inactivate air pathogens such as SARS-CoV-2.¹⁵
 - Deep-UV light-emitting diodes (LEDs) have been shown to inactivate SARS-CoV-2 in suspensions and aerosols within short irradiation times.¹⁶

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems and Air Filtration (Cont.)

- In a study evaluating various HVAC operation strategies for office buildings, researchers compared the effectiveness of the different HVAC filters.¹⁷
 - MERV 13 filtration reduced virus concentration by 10% when compared to MERV 10 filtration.
 - 100% outdoor air reduced virus concentration by 11% compared to MERV 10 filtration but consumed more energy.
 - HEPA filtration negatively effected indoor air quality and increased the average virus concentration and energy consumption compared to MERV 13 filtration; however, this was because the system was not sized for a HEPA filter.
- Some studies have demonstrated the effectiveness of portable devices in reducing the spread of SARS-CoV-2
 - A model assessing the use of portable air cleaners (PACs) in reducing COVID-19 infection in poorly ventilated scenarios found that placing PACs in the center of a room (assessed rooms different sizes: 56m³, 120m³, and 230.4 m³) provides the optimal location for reducing the risk of infection.¹⁸

Studies About the Effects of Ventilation on SARS-CoV-2

HVAC Systems and Air Filtration (Cont.)

- Researchers examining the effectiveness of PACs with high-efficiency particulate air filters (used in addition to standard HVAC and heating) found that aerosols were cleared from a small room 5 times faster than in a room with HVAC alone.¹⁹
 - The addition of 2 devices in a single-bed hospital room increased cleared aerosols from the room 3 times faster than with HVAC alone.
- Results of a study of the use of portal air filtration in a mock classroom with limited ventilation they effectively reduced localized and whole-room (depending on positioning) particle concentration.²⁰
- In another study PACs were shown to be effective in reducing exposure to airborne diseases. Researchers highlighted key considerations that can impact their effectiveness, including location of the PAC, the PAC settings, and the room set-up.²¹

Studies About the Effects of Ventilation on SARS-CoV-2

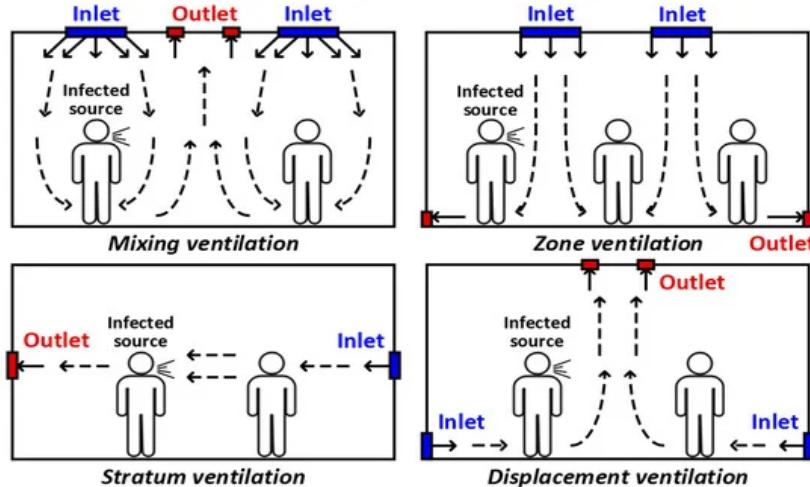
Transportation

- Several studies have been conducted to assess the ventilation of various modes of transportation and the transmission of SARS-CoV-2.
 - A study of air exchange rates (ACH) and advection–diffusion of CO₂ and aerosols in a bus showed that a moving bus with its windows open saw an average 92% reduction in SARS-CoV-2 infection risk (without the need for ventilation fans).²²
 - Another study examining various HVAC and natural ventilation configurations impact the spread of SARS-CoV-2 in a public transit bus noted the importance of also considering the flow dynamics of the bus to accurately determine the best strategy.
 - Findings showed that having the windows closed and the cabin HVAC set to high reduced spread from infected passengers.
 - Opening the window just rear of the driver limited the spread of the driver's aerosols throughout the bus.²³
 - Findings from a simulation study of SARS-CoV-2 risk in a car cabin indicated that several factors must be considered to minimize infection risk, including the ventilation mode, HVAC flow rate, position of the infected subject, and expiratory activity (e.g., talking, coughing).²⁴

Studies About the Effects of Ventilation on SARS-CoV-2

Other General Findings

- A study comparing different ventilation strategies found stratum ventilation to be the optimal strategy compared to others, as it significantly reduces the concentration of contaminants in the breathing region and decreases the risk of airborne transmission (see Figure).¹¹
- Another study simulating different ventilation strategies in an office building found that no ventilation and single ventilation were associated with higher probabilities of viral (e.g., SAR-CoV-2) infection, while cross- and mechanical ventilation were associated with degrees of risk that vary depending on the location in the room.²⁵



Source: Ren C, Zhu H-C, Cao S-J. Ventilation Strategies for Mitigation of Infection Disease Transmission in an Indoor Environment: A Case Study in Office. *Buildings*. 2022;12(2):180.

Studies About the Effects of Other Mitigation on SARS-CoV-2

Studies About the Effects of Other Mitigation Strategies on SARS-CoV-2

Practical Applications of Other Mitigation Strategies

- A randomized, controlled trial assessed SARS-CoV-2 transmission prevention strategies with attendees of a live indoor concert on May 29, 2021 in Paris, France.²⁶
 - The researchers noted that a trial study during a large indoor event held in December 2020 in Berlin demonstrated the effectiveness of implementing same-day rapid test and N95 mask wearing; however, they presented logistical challenges.
 - Findings showed that a multipronged prevention strategy successfully prevented the spread of SARS-CoV-2 during the large gathering without employing physical distancing. The strategy involved systematic antigen screening within 3 days preceding the event, medical mask wearing, and optimized ventilation in the venue.
- Another investigation of SARS-CoV-2 transmission in a large indoor convention held November-December 2021 in New York City found that employing prevention strategies such as vaccination requirements, enforcement of mask use, and avoidance of unmasked indoor settings, as well as the use of HEPA filtration at the venue contributed to the minimal transmission of virus.²⁷

Studies About the Effects of Other Mitigation Strategies on SARS-CoV-2

General Findings

- Studies continue to show evidence that mitigation strategies such as physical distancing, mask use, hand hygiene, and disinfection can be effective in minimizing the risk of SARS-CoV-2 transmission.
 - A study using a risk assessment model to quantify the impact of several mitigation strategies in an enclosed food manufacturing facility found that a bundled intervention (room air changes, ≥ 2 meters physical distancing, universal mask use, hand hygiene, and surface disinfection) reduced SARS-CoV-2 transmission risk <1% for an 8-hour cumulative exposure.²⁸
 - Another study of the use of face masks in California from February-December 2021 found consistent use of a face mask or respirator in indoor public sessions to be effective in lowering the odds of SARS-CoV-2 transmission.²⁹
 - In a study that simulated the effectiveness of COVID-19 mitigation strategies in an elementary school, strategies such as masking, and vaccination were effective in reducing SARS-CoV-2 transmission; local case incidence should be considered before reducing these strategies.³⁰

What Research is Still Needed About the Impact of Ventilation and Other Mitigation Strategies on SARS-CoV-2?

- Consensus on how best to configure, upgrade, or design ventilation systems to mitigate the spread of SARS-CoV-2
- How results may differ if ventilation-related studies used SARS-CoV-2 instead of surrogate substances (e.g., carbon dioxide).
- How to best to utilize ultraviolet germicidal irradiation to reduce virus particles in a space.
- Regarding natural ventilation, determining what configuration (e.g., opening adjacent windows or windows across from each other) is more effective at ventilating a space.
- The effect of wind speed and direction on natural ventilation and, consequently, transmission risk.
- Best practices for balancing energy efficiency with increased ventilation rates (and increased energy use) to mitigate transmission risk.
- The costs and benefits of all ventilation methods that could be used to reduce infection risk.
- Practical applications of varying ventilation strategies in real-life settings.
- The continued use of non-pharmaceutical interventions in mitigating the spread of SARS-CoV-2.

Key CDC Resources About Ventilation to Mitigate SARS-CoV-2

- [Ventilation in Buildings](#)
- [COVID-19 Resources for Workplaces & Businesses](#)
- [Improving Ventilation in Your Home](#)
- [Interactive Home Ventilation Tool](#)
- [Ventilation and Coronavirus \(COVID-19\)](#) (Environmental Protection Agency resource)

HOW THIS BRIEFING WAS CREATED (METHODOLOGY)

How This Briefing Was Created

- In January 2021, REALM stakeholders developed Phase 3 research questions. An additional question related to ventilation was added in May 2021. In October 2021, the variants section was refocused on current variants of concern in the US.
- Battelle developed search strings that included variations of the term “SARS-CoV-2” and novel terms for vaccine and variants using Boolean operators. The Boolean operator “AND” was used to separate SARS-CoV-2 and research question terms, while different variations of the virus name and keywords related to the research question were grouped by category using parentheses and the Boolean operator “OR” (e.g., ["SARS-CoV-2" OR "2019-nCoV" OR "COVID-19"] AND [vaccine OR variant]). Search strings are included in the appendix.
- Battelle developed research question keywords using ad hoc test searches and comparison against known relevant articles. Databases were selected (Scopus, SciTech, Web of Science, and MEDLINE) to provide comprehensive search capacity and inclusion of smaller databases.
- The initial search string included a time criterion to capture articles published in January 2021 and after. Subsequent searches were executed on weekly durations. Note: when the ventilation research question was added in May 2021, articles were searched from 01 January 2021 forward to cover the same time period as the other research questions.
- In June 2022, a final briefing with reduced scope (focusing only on ventilation) was developed using literature published from 01 January 2022 to 27 May 2022.

How This Briefing Was Created (cont.)

- Battelle staff reviewed the titles and abstracts of search results to select those most relevant to the research questions for additional examination.
- Battelle staff analyzed the relevant articles to identify key subtopics and prioritize high-value articles. Summaries of the articles, organized by subtopic, were presented to OCLC, IMLS, and REALM working groups for feedback.
- Battelle summarized the results for this briefing, which is a standalone report that includes relevant research findings published 01 January to 27 May 2022.

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APPENDIX: SEARCH STRINGS

Database	Strategy: Effects of Ventilation on Spread of SARS-CoV-2
Scopus	(((TITLE-ABS ((coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV")) AND TITLE-ABS ((spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc* OR interven* OR npi OR eliminat* OR dilut* OR control* OR inactivat* OR prevent*)) AND TITLE ((indoor* OR office* OR school* OR occupational OR built OR "climate controlled" OR confine* OR enclosed* OR transit OR cabin OR bus OR ambient OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa OR uv* OR ultraviolet* OR thermal OR equipment))) AND NOT TITLE-ABS (therap* OR pollution OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR phenotype OR clinical OR polymerase OR rna OR dna OR sero* OR socio* OR biosensor OR microfluid* OR chip OR mining OR tourism OR stress* OR detect* OR transplant OR coating OR nano*)) AND PUBYEAR > 2021)
SciTech	(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV" (Title) or coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV" (Abstract)) AND (spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc* OR interven* OR npi OR eliminat* OR dilut* OR control* OR inactivat* OR prevent* (Title) or spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc* OR interven* OR npi OR eliminat* OR dilut* OR control* OR inactivat* OR prevent* (Abstract)) AND (indoor* OR office* OR school* OR occupational OR built OR "climate controlled" OR confine* OR enclosed* OR transit OR cabin OR bus OR ambient OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa OR uv* OR ultraviolet* OR thermal OR equipment (Title)) NOT (therap* OR pollution OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR phenotype OR clinical OR polymerase OR rna OR dna OR sero* OR socio* OR biosensor OR microfluid* OR chip OR mining OR tourism OR stress* OR detect* OR transplant OR coating OR nano* (Title) or therap* OR pollution OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR phenotype OR clinical OR polymerase OR rna OR dna OR sero* OR socio* OR biosensor OR microfluid* OR chip OR mining OR tourism OR stress* OR detect* OR transplant OR coating OR nano* (Abstract)) and 2022 (Publication Years) and Patent (Exclude – Document Types)
Web of Science	((ti:coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") OR ab:(coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV")) AND ((ti:spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc* OR interven* OR npi OR eliminat* OR dilut* OR control* OR inactivat* OR prevent*) OR ab:(spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc* OR interven* OR npi OR eliminat* OR dilut* OR control* OR inactivat* OR prevent*)) AND ti:(indoor* OR office* OR school* OR occupational OR built OR "climate controlled" OR confine* OR enclosed* OR transit OR cabin OR bus OR ambient OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa OR uv* OR ultraviolet* OR thermal OR equipment)) NOT ((ti:therap* OR pollution OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR phenotype OR clinical OR polymerase OR rna OR dna OR sero* OR socio* OR biosensor OR microfluid* OR chip OR mining OR tourism OR stress* OR detect* OR transplant OR coating OR nano*) OR ab:(therap* OR pollution OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR phenotype OR clinical OR polymerase OR rna OR dna OR sero* OR socio* OR biosensor OR microfluid* OR chip OR mining OR tourism OR stress* OR detect* OR transplant OR coating OR nano*)) NOT (Wire Feeds AND Trade Journals AND Magazines) 2022-01-01 - Current
MEDLINE	(TI (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV") OR AB (coronavir* OR covid OR "COVID-19" OR "SARS-CoV-2" OR "2019-nCoV")) AND (TI (spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc* OR interven* OR npi OR eliminat* OR dilut* OR control* OR inactivat* OR prevent*) OR AB (spread* OR transmi* OR persist* OR mitigat* OR purif* OR reduc* OR interven* OR npi OR eliminat* OR dilut* OR control* OR inactivat* OR prevent*)) AND (TI indoor* OR office* OR school* OR occupational OR built OR "climate controlled" OR confine* OR enclosed* OR transit OR cabin OR bus OR ambient OR hvac OR merv OR filter* OR filtrat* OR ventilat* OR hepa OR uv* OR ultraviolet* OR thermal OR equipment) NOT (TI (therap* OR pollution OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR phenotype OR clinical OR polymerase OR rna OR dna OR sero* OR socio* OR biosensor OR microfluid* OR chip OR mining OR tourism OR stress* OR detect* OR transplant OR coating OR nano*) AND AB (therap* OR pollution OR hospital* OR nosocomial OR animal OR wastewater OR sewage OR "intensive care" OR phenotype OR clinical OR polymerase OR rna OR dna OR sero* OR socio* OR biosensor OR microfluid* OR chip OR mining OR tourism OR stress* OR detect* OR transplant OR coating OR nano*))

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